

CHARACTERIZATION AND IDENTIFICATION OF SPILLED RESIDUAL
FUEL OILS BY GAS CHROMATOGRAPHY AND INFRARED SPECTROPHOTOMETRY

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16. Abstracts Oil discharges and spills from industrial plants and ships impart unpleasant taste and odor to water and to game fish and fowl, as well as affect the amenities of beach and recreational facilities. For enforcement actions, it has been useful not only to identify the source of oil spills in the streams, but also to characterize first the petroleum product involved. Methods developed in the last two years at the Analytical Quality Control Laboratory are described; the author presents a workable scheme for the characterization and identification of residual oil pollutants found in surface waters. A powerful aid for the characterization of fuel oil products is stressed. Identify with gas chromatographic and infrared data is given in an elaborate fashion and comparisons are made in the absence of extremely expensive analytical equipment.			
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CHARACTERIZATION AND IDENTIFICATION OF SPILLED RESIDUAL
FUEL OILS BY GAS CHROMATOGRAPHY AND INFRARED SPECTROPHOTOMETRY

INTRODUCTION

Oil discharges and spills from industrial plants and ships give unpleasant taste and odor to potable water, game fish and fowl. They also affect the appearance of beaches and recreational facilities. A tragic example of these effects was the pollution caused by crude oil spilled on the coasts of England after the Torrey Canyon disaster.

Though most spills are of smaller magnitude and may result from accidental or intentional action, the frequency of these smaller spills has increased. Damage to flora, water fowl, fish and recreational facilities have become visibly pronounced ⁽⁴⁾. Brown et al. ⁽²⁾ used spent media from the microbial degradation of crude and lube oils and obtained bioassay results which imply water-soluble materials produced are toxic to fish. The urgency of the problem dictates that procedure for detection, characterization, and identification of oil pollutants be established to forewarn of impending health hazards and to establish responsibility for violations of water quality standards. Control Procedures may then be exercised.

For enforcement actions, it has been useful not only to identify the source of oil spills in the streams, but also to characterize first the petroleum product involved.

Rosen and Middleton ⁽¹⁶⁾ identified refinery wastes by analyzing the paraffinic and aromatic fractions resolved by means of elution analysis of the adsorption columns. Mahler and Greenberg ⁽¹⁴⁾ reported that infrared spectrophotometry and flame ionization detection gas chromatography are useful enforcement tools; however, illustrative details of the two techniques are not shown for characterization. Recently, Brunnoch et al. ⁽³⁾ described the procedures for analyzing the n-paraffin content of beach pollutants by FID gas chromatography used in conjunction with other methods to identify weathered crudes. Examined crude oils contained unusually high percentages of n-paraffins.

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More recently, Blumer and Ehrhardt ⁽¹⁾ reported the identification of oil spills by means of gas chromatographic and spectrometric data. Ratios of absorbances at different wavelengths of the ultraviolet spectra are said to have diagnostic value. Kawahara ⁽⁶⁾ reported on a new method for identifying specific minor components of crude oils, weathered crudes, and heavy residual fuel oils by means of electron capture gas chromatography. Distinctive and characteristic patterns in the chromatograms are noted for each of the three types of petroleum materials.

This paper describes methods developed at the National Environmental Research Center, Cincinnati, Ohio in the last two years and presents a workable scheme for the characterization and identification of the residual oil pollutants found in surface waters.

EXPERIMENTAL

1. Procedure

a. Collection

Oily material was collected by surface skimming of the water with a clean, wide-mouth bottle. Bottles were filled to the top. Reference samples were obtained from shore facilities, and all samples were preserved in a refrigerator. Air and light were excluded when possible.

b. Extraction

The water sample and reference were extracted in a similar manner with chromatographic grade dichloromethane. The extracts were washed with water, dried over sodium sulfate and filtered. The filtrate was collected in a 300 ml round bottom flask, equipped with a standard tapered 24/40 ground glass joint.

c. Concentration

A round bottom flask containing the dried dichloromethane extract was attached to an all-glass distillation set-up, and the solvent was evaporated off. Completeness of solvent removal was monitored by I.R. examination. When bands appeared at 7.85 μ and 13.55 μ , the solvent removal process was continued until the two bands no longer appeared in the infrared spectrum. Extracts of the reference material and the water sample were treated similarly in the concentration procedure.

2. Equipment

a. Apparatus

The Perkin-Elmer 137 and 621 instruments were used for the infrared spectrophotometric analysis. Operating modes were designated previously. The Perkin-Elmer gas chromatograph, Model 800, with flame ionization detector was used with an 8-foot by 0.25-inch aluminum column containing 5% DC-200 supported on Gas Chrom Q of 60-80 mesh size and was programmed from 110°C to 224°C. Program rate was 10°C per minute. Injector temperature was 205°C and the detector temperature was 130°C. Hydrogen pressure was 12 lbs.

per sq. in., air was 7 lbs. per sq. in., and helium was 22 lbs. per sq. in. Sensitivity was set at attenuation of 1×10^3 and 5×10^2 .

The Perkin Elmer gas chromatograph, Model 900, was used with a 50 foot by 0.02-inch steel column coated with DC-200 and programmed from 80°C to 170°C. Program rate was 30°C per minute. Injector temperature was 320°C, and the detector temperature was 260°C. Hydrogen pressure was 18 lbs. per sq. in., air was 35 lbs. per sq. in., and helium was 12 lbs. per sq. in.

The Dohrmann 2400 Graphmatic with the flame ionization detector was used with an 8-foot by 0.125-inch stainless steel column containing 4% S.E.-30 supported on Chromosorb G, non-acid washed, of 60-80 mesh size. Temperature was programmed from 100°C to 225°C and the rate was 15°C per minute. Hydrogen pressure was 10.5 lbs. per sq. in., air was 10 lbs. per sq. in., and helium was 50 lbs. per sq. in. Sensitivity was set at an attenuation of 1×8 . Recorder speed was 1 inch per 2 minutes.

b. Chemicals

All reagents were purchased from Burdick and Jackson Laboratories, Inc. and were of special purity grade. The OC samples were dissolved 10% by volume in chloroform. One μ l injection was made from the dilution.

3. Preliminary Procedures

About 0.2 gram of the thoroughly dried residue was taken to determine if it was completely soluble in five ml of hexane or in chloroform. A light beam may be necessary to determine the degree of clarity of the dark solution; finely-divided organic sediment present in the hexane solvent infers that the petroleum product is hexane-soluble. If it is only readily soluble in chloroform, it is assumed to be a crude, a grease, a heavy residual fuel oil (No. 6, No. 5, or No. 4) or an asphalt. If the material is soluble in hexane and chloroform, the material is assumed to be one of the following: light or heavy naphtha, kerosene, gas oil, white oil, diesel

oil, jet fuel, cutting oil, motor oil or cutter stock.

b. Density

The density of the oil is measured by the pycnometric methods ASTM D-941 or ASTM D-1217.

4. Infrared

The dried residue is transferred to a 0.025 mm demountable infrared cell (or a prism for asphalt) and is scanned between wavelengths of 2.5 μ and 15 μ . The sample spectrum is compared with the reference spectrum.

For the characterization of asphalts, fuel and residual fuel oils, and lube oils, the infrared absorbances (Kawahara and Ballinger, 1970) are measured at the following frequencies: 3050 cm^{-1} , 2925 cm^{-1} , 1600 cm^{-1} , 1375 cm^{-1} , 810 cm^{-1} , 720 cm^{-1} . The comparative evaluation of the two ratios, $\frac{810 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$ versus $\frac{810 \text{ cm}^{-1}}{720 \text{ cm}^{-1}}$ is made empirically. For identification purposes, the spectra of the collected oil slick residue and reference oil are compared along the entire spectral region between 2.5 μ and 15 μ .

5. Gas Chromatography

Gas chromatography is one of the most efficient general methods for separating components in a mixture and is especially useful in the analyses of volatile petroleum products. For classified, volatile petroleum products, such as naphtha, gasoline (5,8,12,13), jet fuel, kerosene (13), No. 1 fuel oil, No. 2 fuel oil (15), No. 5 fuel oil (7), crude oils (1,3,6), No. 6 fuel oil (6), petroleum jelly and some lube oils, the recovered residual material may be analyzed by this method. Because volatility is a strong characteristic for eight of the above ten oil products, a portion representing the volatiles of the gas chromatogram from the reference sample will be missing in the chromatogram of the weathered, unknown petroleum sample (9). The effects of exposure, temperature, fuel volatility, and water solubility, and air and biological oxidations are considered in evaluating the comparison. If the gas chromatogram of the unknown shows qualitative and quantitative match

with the reference sample, except for peaks which represent compounds of high volatility, solubility in water, or biodegradation, the two products may be judged as being from the same source (3,9).

The use of the gas chromatograph as a means to identify heavier products, such as very heavy residual fuel oils and asphalt, is limited. Gas oils, paraffins, white oils and motor oils can be identified by this method if they are volatile under the conditions used for the g.c. analyses.

Results and Discussion

Table 1 shows the solubility behavior and densities of five oil-water samples collected in the Summer of 1970 after an oil was discharged into one of Lake Erie's tributaries.

TABLE IDensity Values and Solubility Behavior of Isolated
Spill and Source Oils

Sample Label (as rec'd)	Source	Density gm/cc	Solubility	
			Chloroform	Hexane
OC-1	0930: Mouth of tributary	0.972	Soluble	Insoluble
OC-2 (Known)	1200: left tributary out of pipeline of company	0.918	"	"
OC-3 (Known)	1500: Storage tank drain of company	0.982	"	"
OC-4	100 ft. behind surface barrier, 9/12/70	0.931	"	"
OC-5 (Known)	1500: tank truck near tributary	0.973	"	"

As these residual samples are soluble in chloroform but insoluble in hexane, the petroleum product involved in the spill is probably a heavy residual fuel oil (No. 4, No. 5, No. 6), asphalt, grease or crude.

The density value of 0.97 suggests that OC-1, OC-3, and OC-5 are No. 4, No. 5, No. 6 or asphalt materials. The density values of 0.92 and 0.93 suggest that OC-2 and OC-4 are No. 4, No. 5, No. 6 asphaltic materials or crude.

Table II lists density values for the various petroleum products.

TABLE II
TABLE OF DENSITY PROPERTIES OF PETROLEUM
PRODUCTS

Material	Density	API Gravity
Crude	0.857 - 0.976	13.5 - 33.5
High gravity naphtha	0.684 - 0.802	45 - 75
Low gravity naphtha	0.868 - 0.877	30 - 53
Gasoline	0.732 - 0.747	58 - 62
Jet Fuel	0.759 - 0.825	40 - 55
Kerosene	0.797 - 0.825	40 - 46
Gas oil	0.859 - 0.877	30 - 33
White oil	0.866 - 0.882	29 - 32
Motor oil	0.877 - 0.909	24 - 30
Fuel oil #1	>0.849	>35
Fuel oil #2	>0.898	>26
Fuel oil #4	0.844 - 1.006	9 - 36
Fuel oil #5	0.909 - 1.025	6.5 - 24
Fuel oil #6	0.917 - 1.101	-3 to 23
Asphalt	0.947 - 1.147	-8 - 18

Though these tests will not suffice to distinguish one material among many samples, the information is useful for procedural workup of sample and, to a small extent, for characterization. The density value and solubility studies eliminate these products as being No. 2 or No. 1 fuel oil and lubricating oils.

To determine the nature of the five samples, the ratios of infrared absorbances were determined⁽¹⁰⁾. The infrared spectra of the five samples analyzed with the Perkin-Elmer 137 are given in the first two figures.

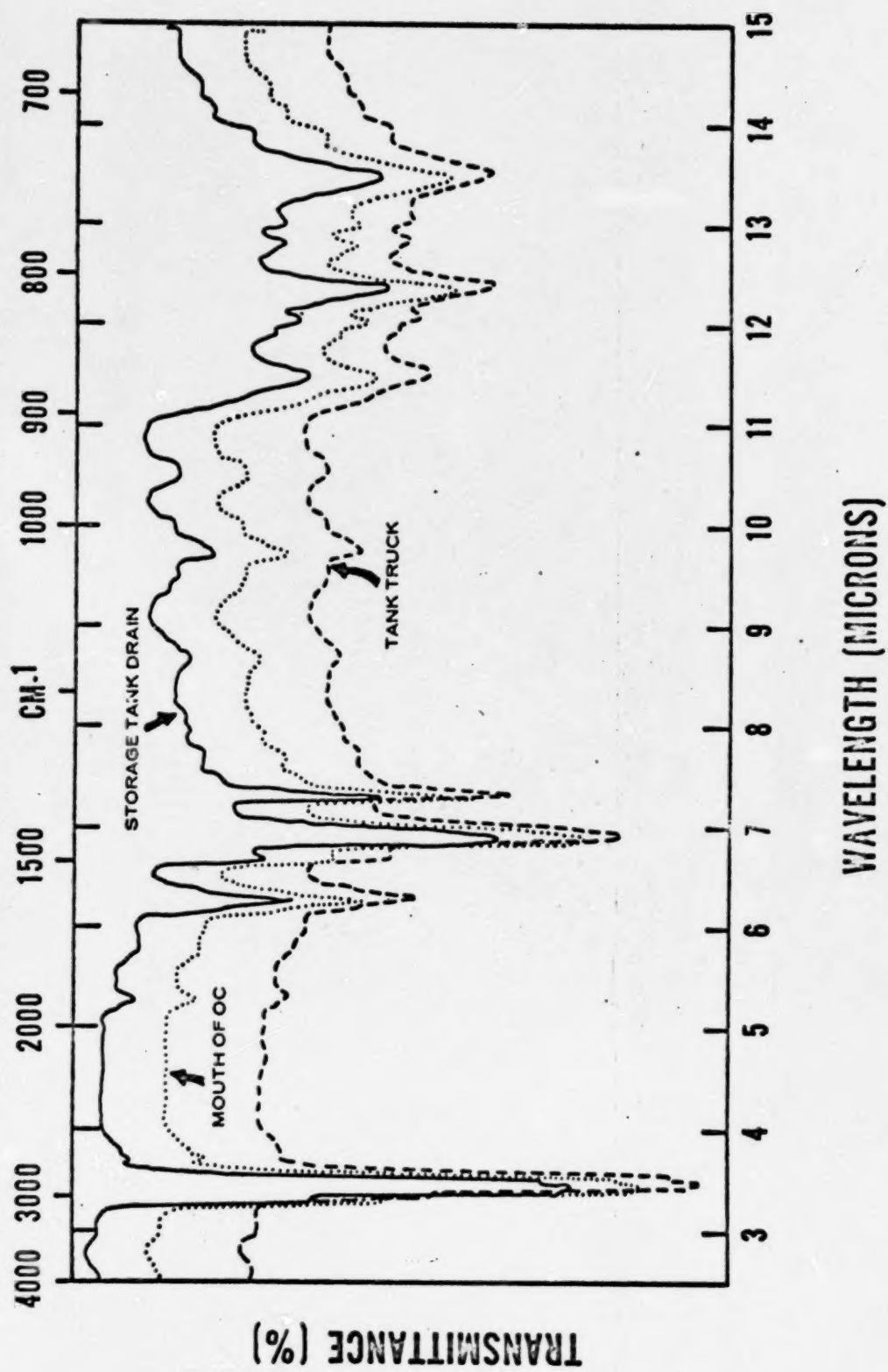
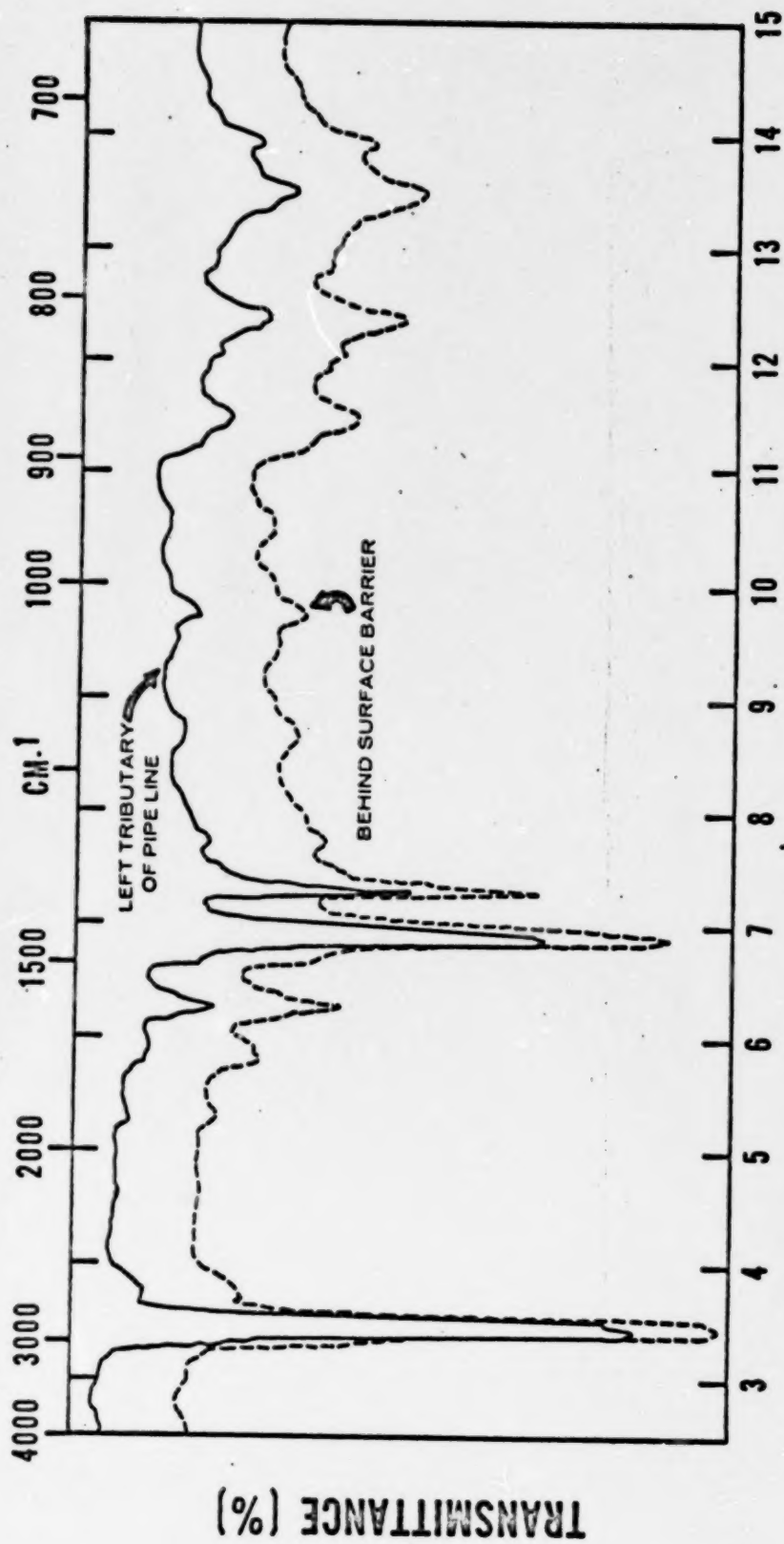


Figure 1



WAVELENGTH (MICRONS)

Figure 2

Comparison of the $\frac{810 \text{ cm}^{-1}}{720 \text{ cm}^{-1}}$ and $\frac{810 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$ values of the five O.C.

(Table III) reveals that OC-1, OC-3, and OC-5 may be similar, while OC-2 and OC-4 are probably paired.

TABLE III

RATIOS OF INFRARED ABSORBANCES OF LUBE OILS,
ASPHALTS, NO. 6 FUEL OILS, AND O.C. SAMPLES

RIA	LUBE OIL	ASPHALT	NO. 6 FUEL OIL	OC-1	OC-2	OC-3	OC-4	OC-5
$\frac{720 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$	0.48	0.28	0.20	0.08	0.11	0.08	0.13	0.07
$\frac{3050 \text{ cm}^{-1}}{2925 \text{ cm}^{-1}}$	0.20	0.22	0.28	0.48	0.25	0.47	0.26	0.42
$\frac{1600 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$	0.11	0.54	0.60	0.90	0.33	0.95	0.48	0.82
$\frac{1600 \text{ cm}^{-1}}{720 \text{ cm}^{-1}}$	0.24	2.05	3.27	11.50	3.05	12.00	3.65	11.50
$\frac{810 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$	0.06	0.25	0.40	0.77	0.32	0.84	0.41	0.76
$\frac{810 \text{ cm}^{-1}}{720 \text{ cm}^{-1}}$	0.12	0.94	2.18	9.80	3.00	10.00	3.18	10.75

Values of 9.80, 10.00, and 10.75 for the $\frac{810 \text{ cm}^{-1}}{720 \text{ cm}^{-1}}$ ratio and 0.77, 0.84 and 0.76 for the $\frac{810 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$ ratio are too large for OC-1, OC-3, and OC-5 to be classified as No. 6 fuel oil (10). Such high values are characteristic of some No. 5 fuel oils or of cutter stock (or mixture).

Commercial samples of eleven No. 5 residual fuel oil and several cutter stocks were studied to determine their ratios of infrared absorbances. Their distinctive values are shown in Table IV.

TABLE IV

RATIOS OF INFRARED ABSORBANCES OF NO. 5 FUEL OILS,
CUTTER STOCK, AND OC-3 SAMPLE

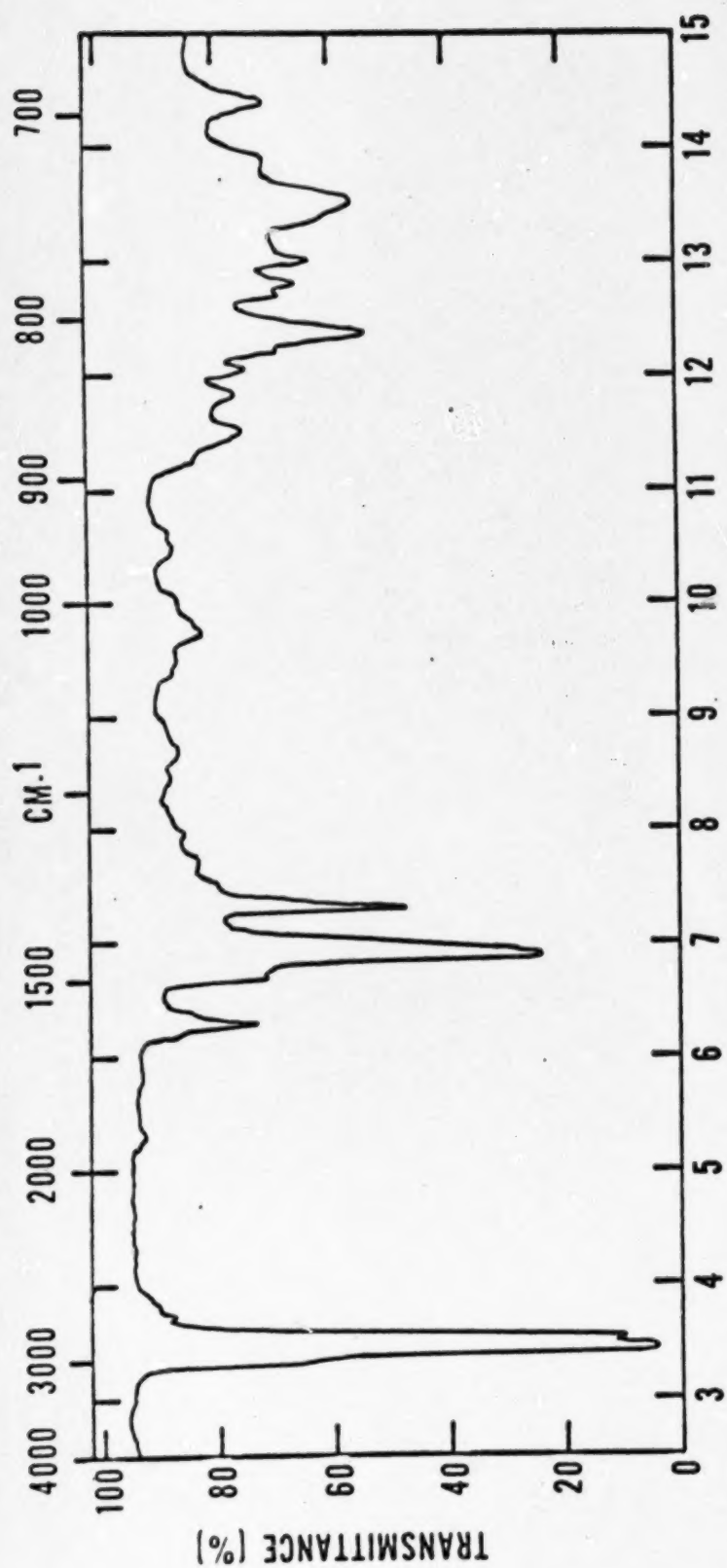
RIA	OC-3 KNOWN	NO. 5 FUEL OIL (P)	CUTTER STOCK (S)	NO. 5 FUEL OIL AVERAGE OF ELEVEN SAMPLES
---	---	---	---	-----
$\frac{720 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$	0.08	0.08	0.07	0.13 ± 0.03
$\frac{3050 \text{ cm}^{-1}}{2925 \text{ cm}^{-1}}$	0.47	0.46	0.60	0.32 ± 0.09
$\frac{1600 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$	0.95	0.95	0.72	0.58 ± 0.21
$\frac{1600 \text{ cm}^{-1}}{720 \text{ cm}^{-1}}$	12.00	11.20	10.20	5.00 ± 2.81
$\frac{810 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$	0.84	0.70	0.85	0.48 ± 0.12
$\frac{810 \text{ cm}^{-1}}{720 \text{ cm}^{-1}}$	10.00	8.20	12.00	3.92 ± 1.90

The $\frac{810 \text{ cm}^{-1}}{720 \text{ cm}^{-1}}$ and $\frac{810 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$ ratio values are far greater than those determined

for No. 6 oils and asphalts. The low values for the first ratio, $\frac{720 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$

designates OC-1, OC-3 and OC-5 as possessing proportionately less methylene rock characteristics or more branching than for No. 6 asphalt or lube oil.

High content of specific aromatics in OC-1, OC-3 and OC-5 is demonstrated by the remaining five ratios of infrared absorbances. All five ratios have high values. Because of their high specific aromatic content, cutter stocks serve as a suitable solvent for heavy residual fuel oils (Figure 3).



WAVELENGTH (MICRONS)

SPECTRUM NO. _____		SPECTRUM NO. _____	
SAMPLE CUTTER STOCK		SAMPLE _____	
6198		1. _____	
PURITY _____		2. _____	
PHASE LIQUID CELL		DATE 5-25-71	
THICKNESS 0.025 mm		OPERATOR KNUEVEN	
REMARKS _____		REMARKS _____	

Figure 3.

On the other hand, OC-2 and OC-4 have values of 0.32 and 0.41 for the $\frac{810 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$ ratio and 3.00 and 3.18 for the $\frac{810 \text{ cm}^{-1}}{720 \text{ cm}^{-1}}$ ratio. These values are more characteristic of No. 6 fuel oils. Indeed the four ratio values, $\frac{720 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$

$\frac{3050 \text{ cm}^{-1}}{2925 \text{ cm}^{-1}}$, $\frac{1600 \text{ cm}^{-1}}{1375 \text{ cm}^{-1}}$, and $\frac{1600 \text{ cm}^{-1}}{720 \text{ cm}^{-1}}$ obtained from the OC-2 and OC-4 infrared

spectra reflect those values representative of No. 6 fuel oil averages given in Table III.

The identification of the source of oil spill can be demonstrated between suspected sources, OC-3 and OC-5, with the pollutant oil, OC-1, following the comparative analyses. All six ratio values of the above three oil samples, OC-1, OC-3 and OC-5 match closely.

Our initial findings obtained with the small prism instrument were confirmed with the use of the large grating infrared spectrophotometer. The odd OC series samples match peak by peak, as shown in Figures 4 and 5.

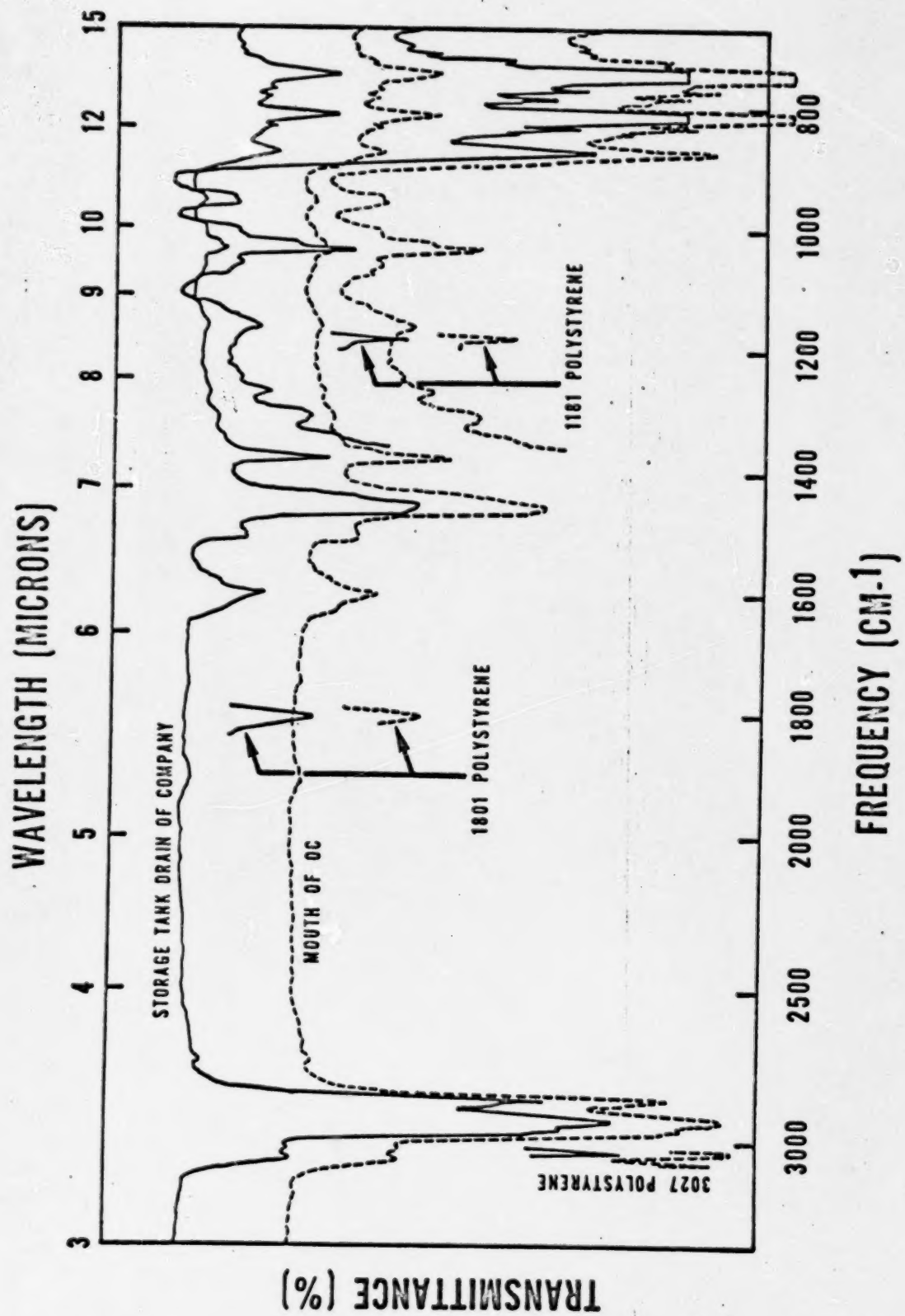
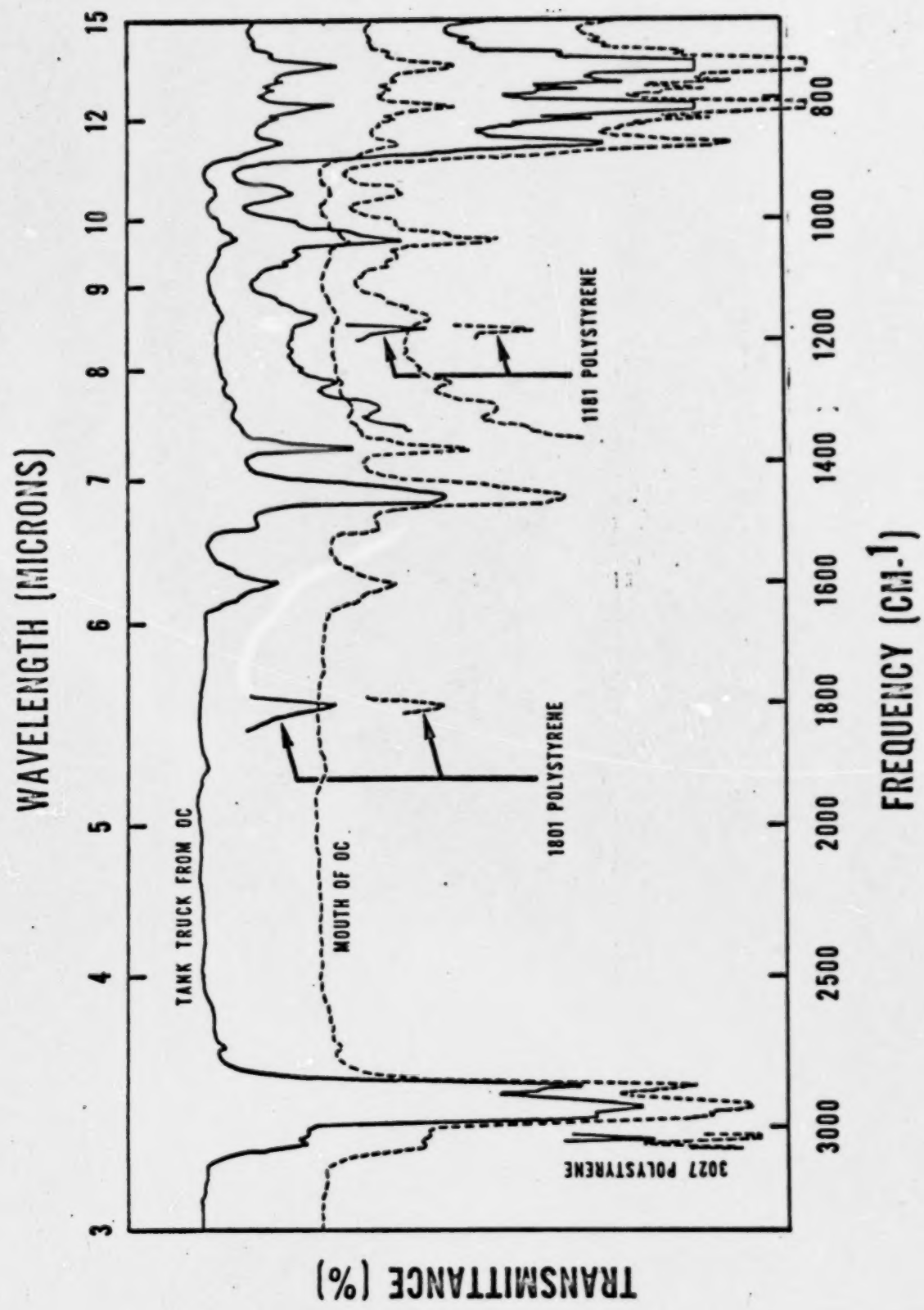


Figure 4



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Figure 5-

OC-2 spectrum was compared to OC-4. These spectra match closely peak-by-peak (Figure 6).

22

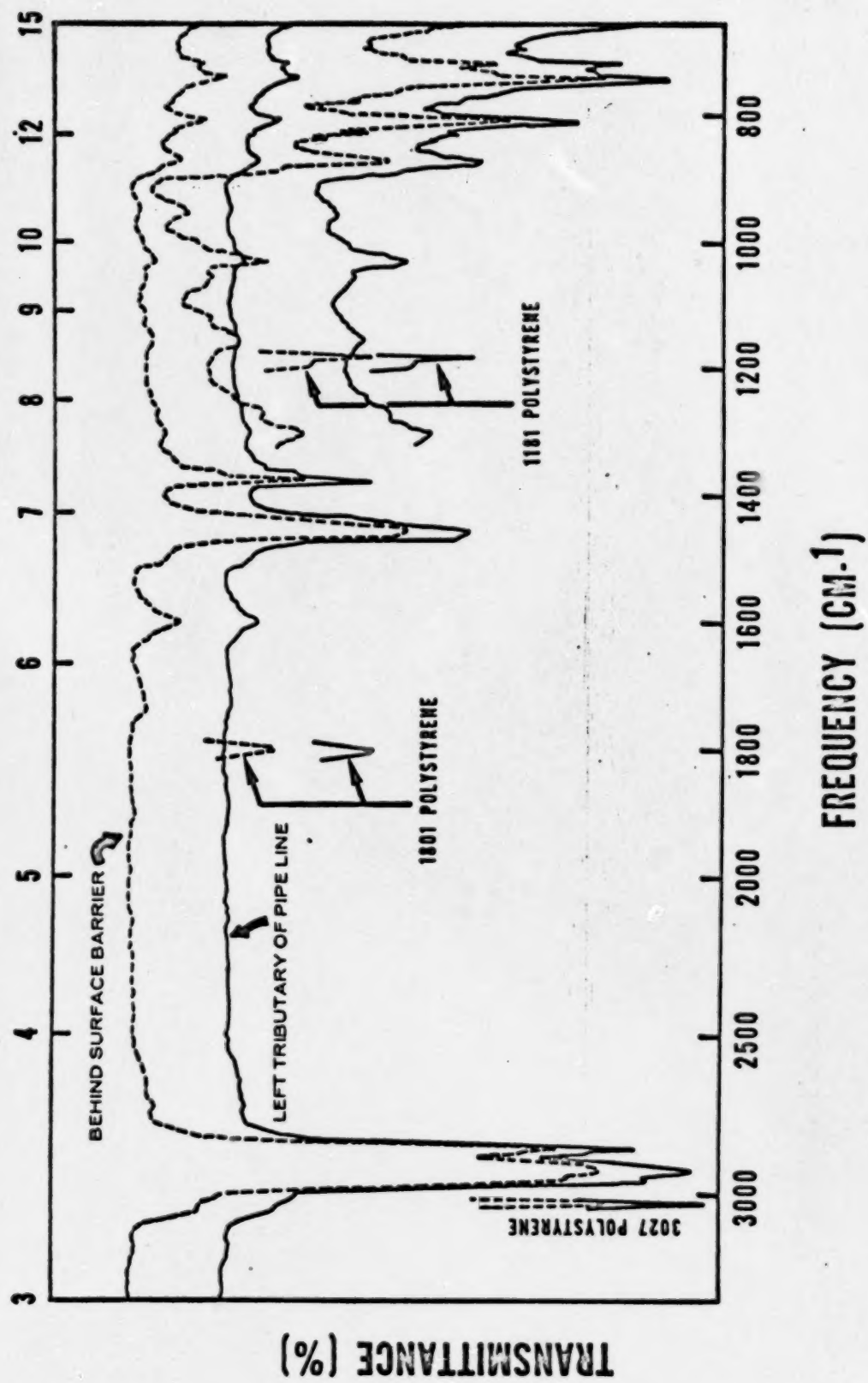
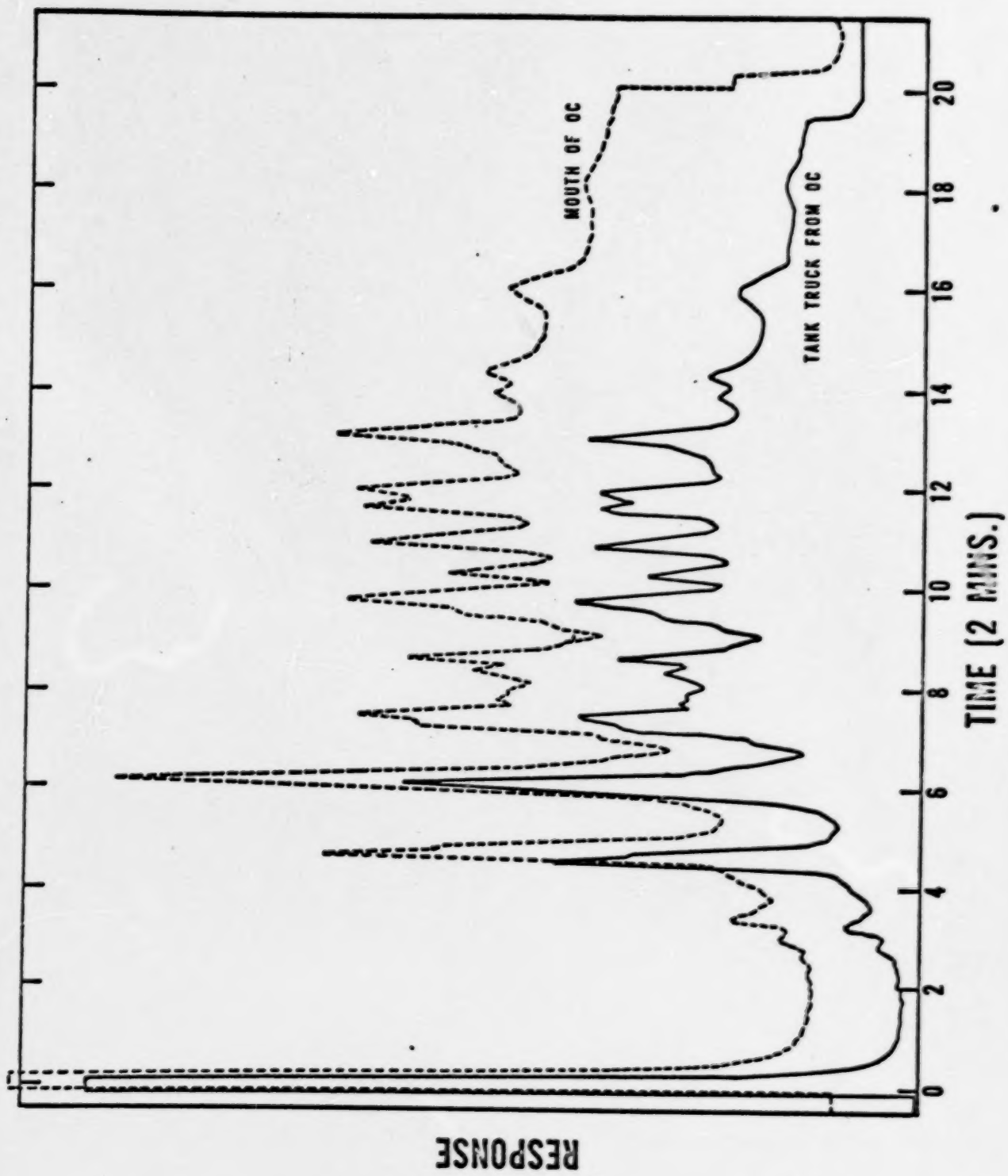


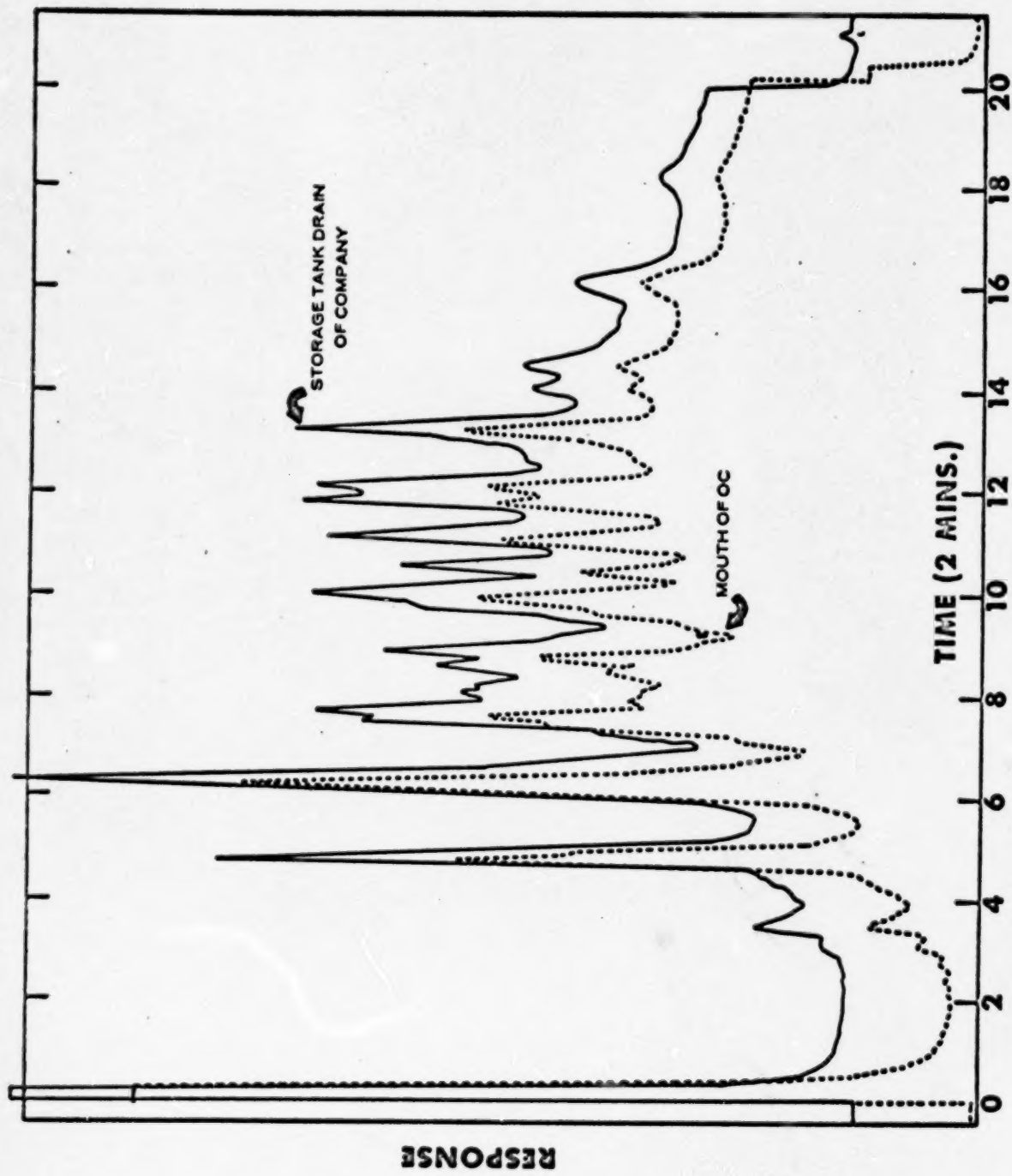
Figure 6

23

To corroborate the infrared findings, analysis of five samples by gas chromatography with a flame ionization detector was made (Figures 7 through 9).

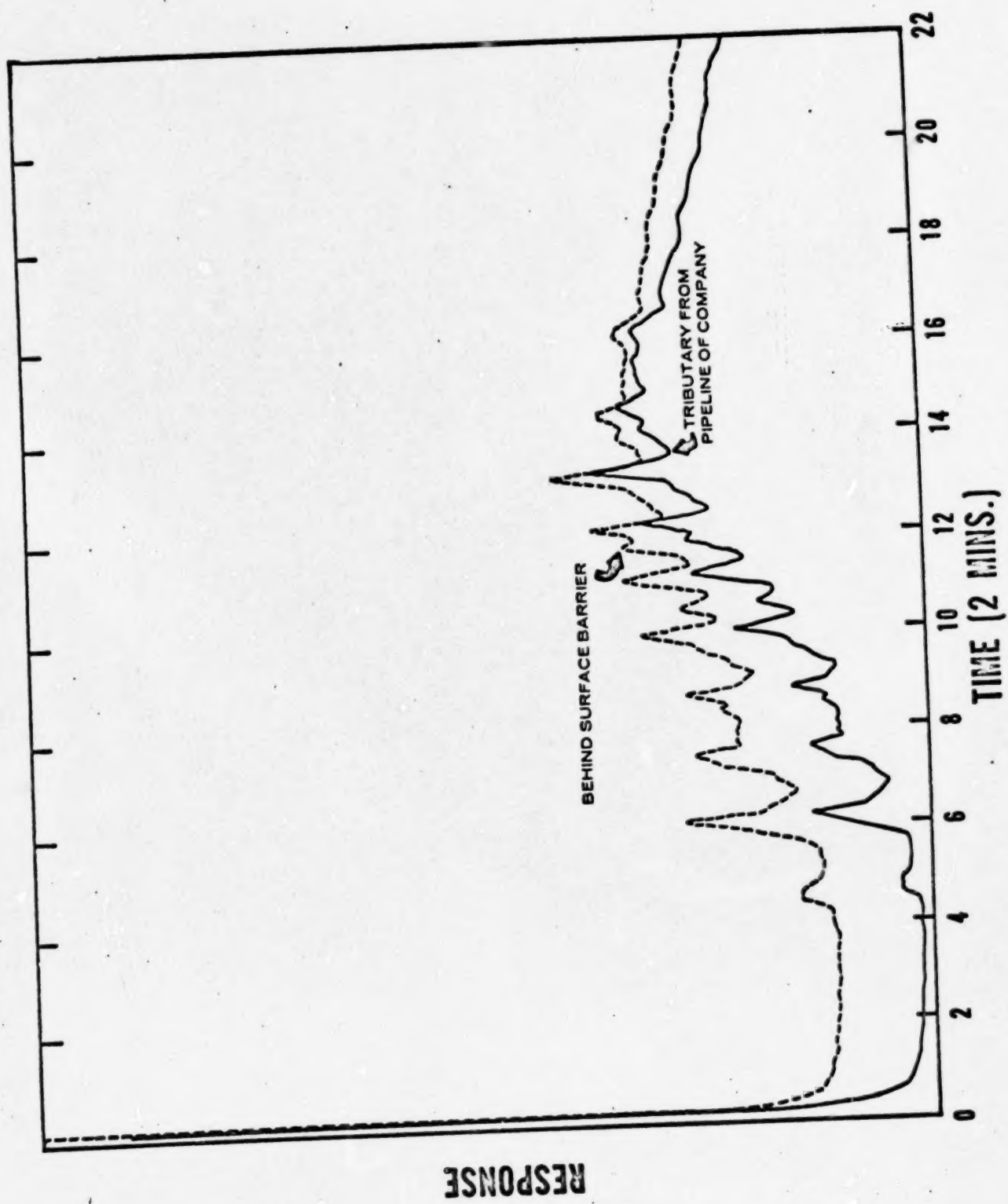
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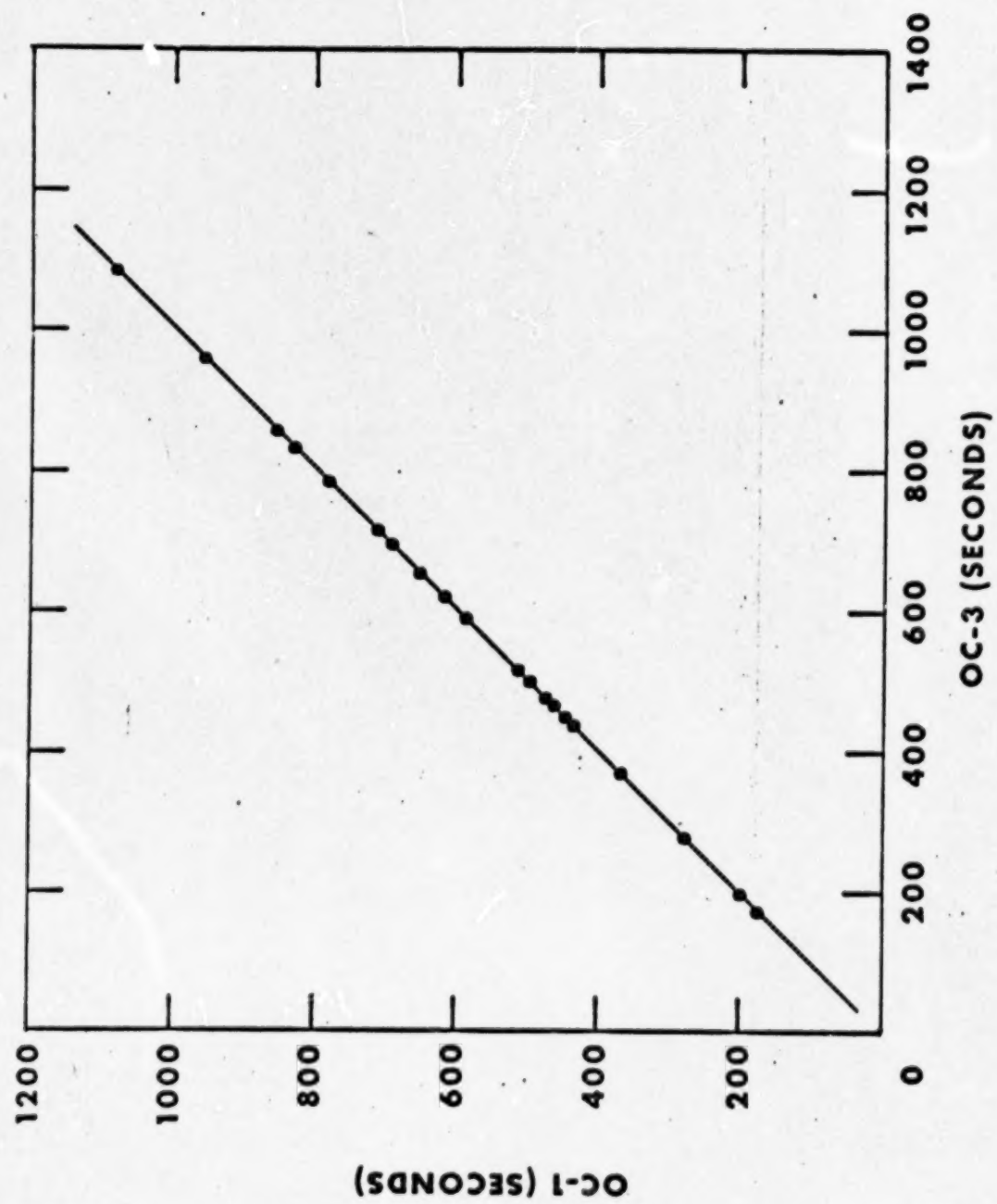
Figure 8



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Figure 9

Excellence of the g.c. retention data is illustrated by the x-y scatter diagram, (Figure 10) which demonstrates agreement of retention times of resolved OC-3 (storage tank drain) peaks with those from the OC-1 (mouth of OC).



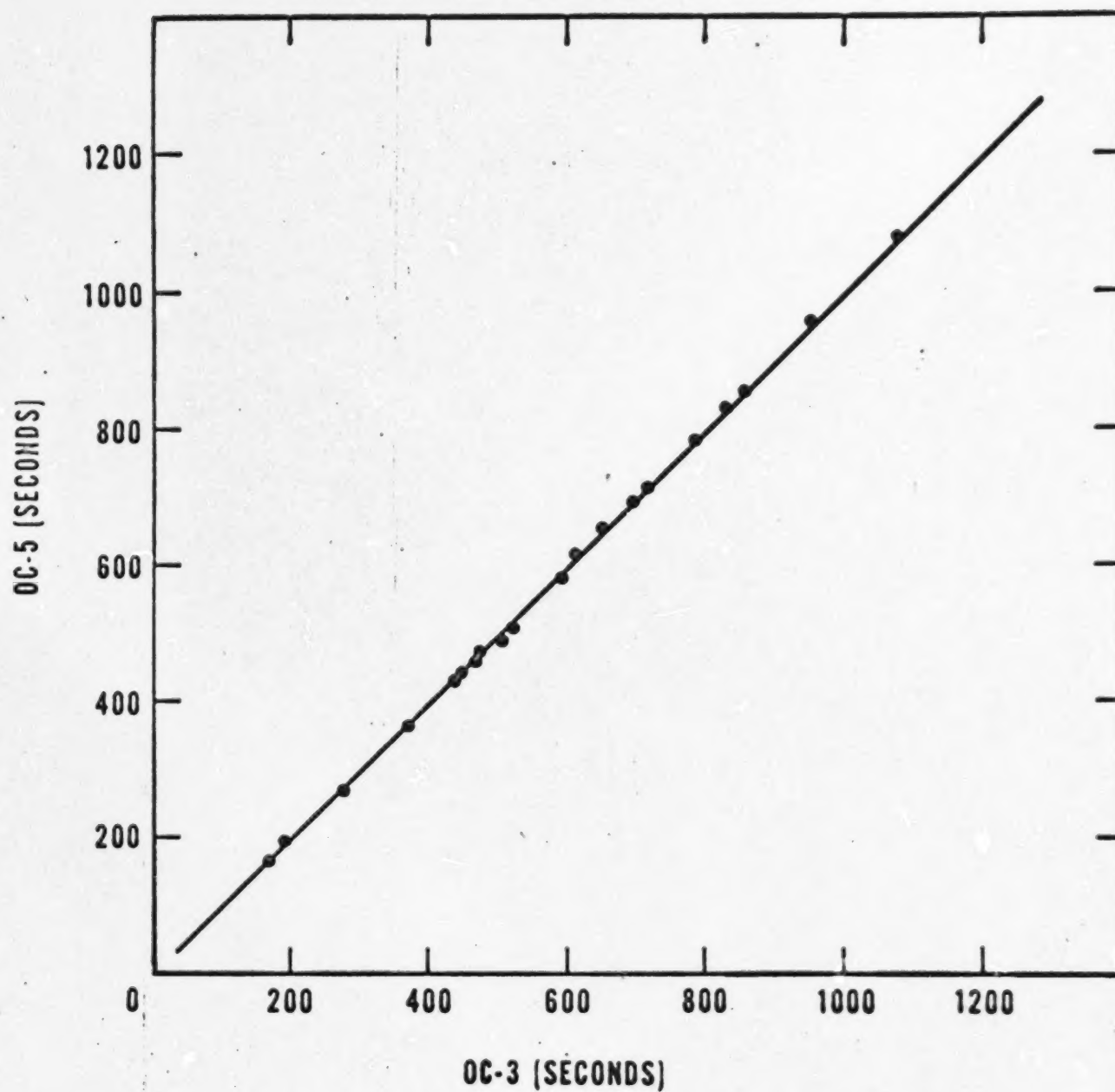
**X-Y SCATTER DIAGRAM
WHICH COMPARES RETENTION TIMES OF SAMPLES OC-1 AND OC-3**

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Figure 10

Excellence of agreement of retention times of twenty, resolved g.c. peaks from OC-3 and OC-1 is indicated by the proximity to the theoretical 45° line of all retention times. This provides additional evidence for uniformity of the OC-1 (mouth of OC) and OC-3 (storage tank drain). The x-y scatter diagram (Figure 11) for OC-3 and OC-5 demonstrated also excellent agreement for uniformity.

X-Y SCATTER DIAGRAM WHICH COMPARES
RETENTION TIMES OF SAMPLES OC-3 AND OC-5



Further evidence for the identity of OC-1 to OC-3 was obtained by demonstrating that gas chromatographic components resolved in both samples were present in similar proportion. The amounts of three resolved g.c. peaks with retention times of 5.85, 7.90, and 13.85 seconds of the OC-1 chromatogram were compared to amounts of corresponding g.c. components of the OC-3 samples. Table V illustrates the amounts of three components (peaks) from the unknown (OC-1) and source sample (OC-3).

TABLE V

Sample	5.85 seconds (a)	7.9 seconds (b)	13.85 seconds (c)
OC-1	.0469	.0674	.0158
OC-3	.0509	.0835	.0175

Ratios of these inherent tags were taken to avoid problems of composition changes during weathering. Table VI illustrates clearly that the ratios of relative amounts of three components in OC-1 are a close match to the ratios of relative amounts of the three components in OC-3.

TABLE VI

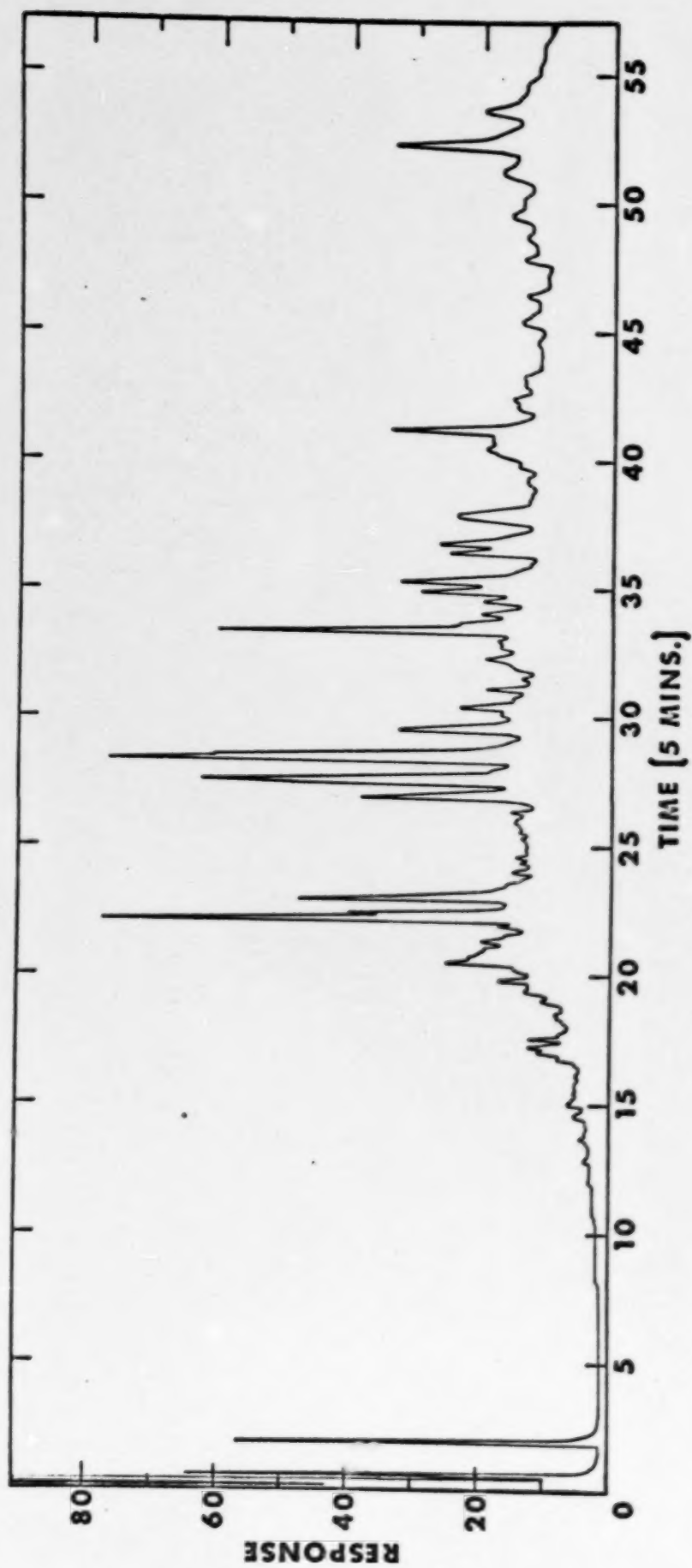
Ratios of Relative Areas of Peaks

<u>Sample</u>	$\frac{a}{c}^*$	$\frac{a}{b}^*$	$\frac{b}{c}^*$
OC-1	2.97	0.696	4.26
OC-3	2.91	0.610	4.75

* a = 5.85 seconds, b = 7.9 seconds and c = 13.85 seconds

Therefore, we can deduce that the a, b, and c components in OC-1 are in same proportion as the a, b and c components are in OC-3.

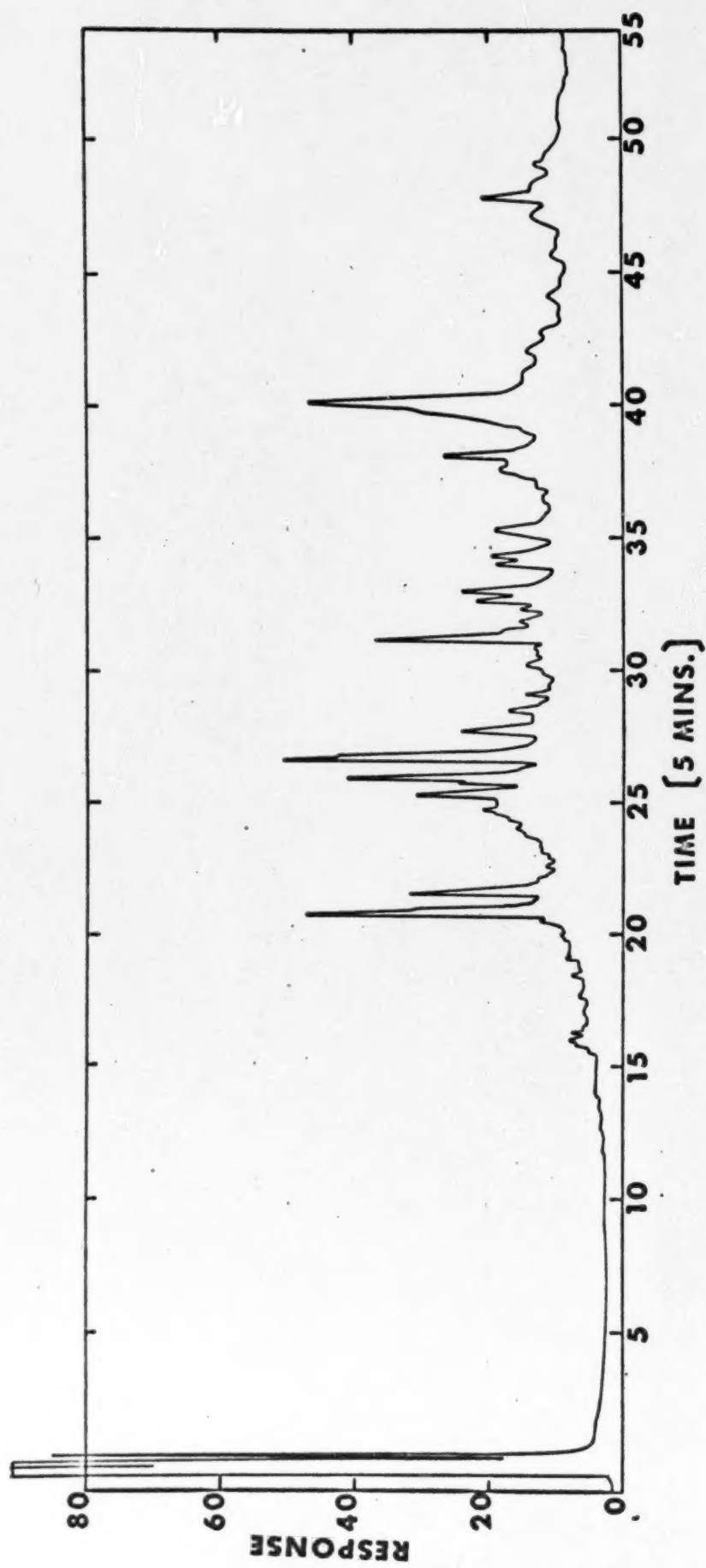
Additional evidence for the similarity of the OC-1 to OC-3 is shown by Figures 12 and 13, that depict the FID gas chromatograms of the unknown and known, respectively, using a Golay, open tubular, wall coated DC-200 column



MOUTH OF OC

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Figure 12



STORAGE TANK DRAIN OF COMPANY

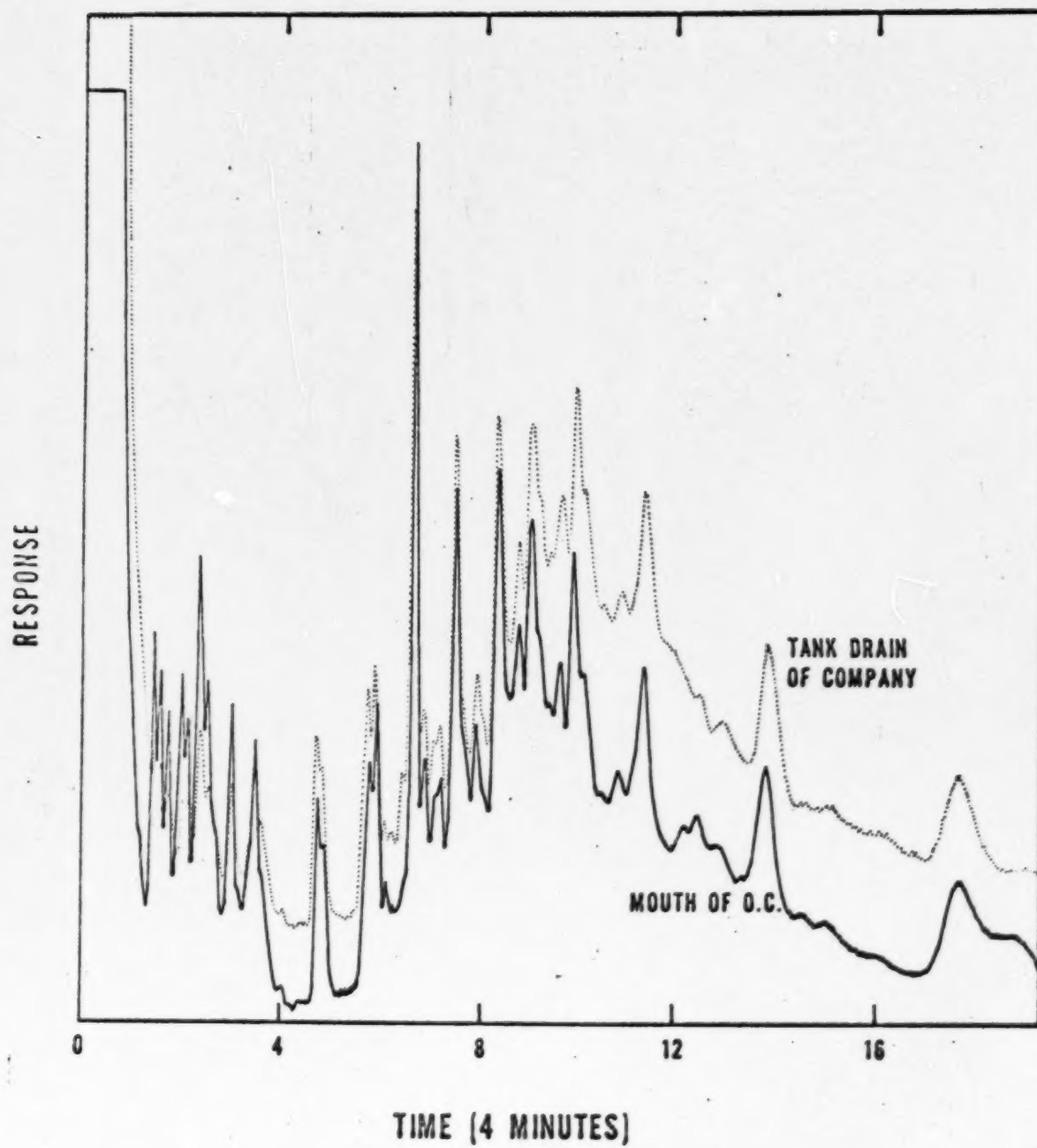
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Figure 13

(there was a slight variance in the gas flow rate). Except for a trace of impurities in the OC-1 at about the twenty minute time, the chromatograms appear similar with respect to peak shape, relative size of peaks, and pattern of peaks in order of appearance.

The OC-1 and OC-3 samples were also analyzed, using the modified procedure of Knight ⁽¹¹⁾. Figure 14 shows the gas chromatograms of the n-paraffinic portion recovered from the sieves. Hexadecane added at 0.05 microgram per microliter is designated by the unusually large peak at 6.5 minutes. The chromatograms show that the normal paraffins from the mouth of O.C. closely match those from the tank drain of the company.

The new pentafluorobenzyl derivative method ⁽⁶⁾ developed for identifying heavy residual fuel oils and related products was tested on OC-2 and OC-4. These materials were observed analytically to contain weak acids that were derivatized readily, fractionated on silica gel columns and analyzed for pentafluorobenzyl ethers and thioethers by means of electron capture gas chromatography. Indeed, OC-4, the spilled pollutant, is shown to be identical to OC-2, the source material, by this new and independent method as the two electron capture gas chromatograms were the same.



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Figure 14

Identity of retention data (x-y scatter diagram), similarity of all F.I.D. and E.C.D. g.c. peak shapes, similar proportion of three selected peaks, similar gas chromatograms of resolved normal paraffins, similar ratios of infrared absorbances and infrared spectra, and other physical measurements have shown that the source of OC-1 sample found in the tributary waters is from the storage tank drain, the OC-3 sample, or from the tank truck, OC-5. The OC-4 oil found behind the surface barrier is derived from OC-2 (from the pipeline of the company).

It has been shown that the ratios of infrared absorbance can be used as a powerful aid for the characterization of fuel oil products, while F.I.D. and E.C.D. gas chromatography are extremely useful in the identification of volatile petroleum products.

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Mention of the products and manufacturers is for identification purposes only and does not imply endorsement by the Environmental Protection Agency.

FIGURE CAPTIONS

- FIGURE 1. Infrared spectra of oil spilled on O.C. stream and two reference samples.
- FIGURE 2. Infrared spectra of oil spilled behind a surface barrier and a reference sample taken from a pipeline.
- FIGURE 3. Infrared spectrum of a cutter stock.
- FIGURE 4. Infrared spectra of oil spilled on the river compared with reference sample from a tank.
- FIGURE 5. Infrared spectra of oil spilled on river compared with reference sample from oil tank truck.
- FIGURE 6. Infrared spectra of oil spilled behind surface barrier compared with reference sample from pipeline.
- FIGURE 7. F.I.D. gas chromatograms of oil found in river compared to reference sample from truck.
- FIGURE 8. F.I.D. gas chromatogram of oil spilled on river compared to reference sample from storage tank.
- FIGURE 9. F.I.D. gas chromatogram of oil found behind surface barrier compared to that from a pipeline of the company.
- FIGURE 10. X-Y diagram which compares retention times of F.I.D. gas chromatogram peaks from OC-1 and OC-3.
- FIGURE 11. X-Y diagram which compares retention times of F.I.D. gas chromatogram peaks from OC-5 and OC-3.
- FIGURE 12. F.I.D. gas chromatogram of the spilled oil using a Golay, open tubular, wall coated DC-200 column.
- FIGURE 13. F.I.D. gas chromatogram of the reference tank sample, using Golay, open tubular, wall coated DC-200 column.
- FIGURE 14. F.I.D. gas chromatograms of n-paraffins separated from spilled oil and tank reference samples.

TABLE 3

R.I.A.	LUBE OIL	ASPHALT	NO. 6 FUEL OIL	NO. 5 FUEL OIL	CUTTER STOCK
$\frac{720 \text{ CM}^{-1}}{1375 \text{ CM}^{-1}}$	.48	.28	.20	.13	.07
$\frac{3050 \text{ CM}^{-1}}{2925 \text{ CM}^{-1}}$	.20	.22	.28	.32	.60
$\frac{1600 \text{ CM}^{-1}}{1375 \text{ CM}^{-1}}$	.11	.54	.60	.58	.72
$\frac{1600 \text{ CM}^{-1}}{720 \text{ CM}^{-1}}$	.24	2.05	3.27	5.00	10.20
$\frac{810 \text{ CM}^{-1}}{1375 \text{ CM}^{-1}}$	.06	.25	.40	.48	.85
$\frac{810 \text{ CM}^{-1}}{720 \text{ CM}^{-1}}$	.12	.94	2.18	3.92	12.00

OC-2

DERIVATIVE
ADSORPTION

ECGC.

1.15
1.25

2.3

4.2

4.4

6.35

9.2

17.4

